Journal of Orthopaedic Trauma
Vol. 6, No. 3, pp. 294–300

A Comparison of Unicortical and Bicortical End Screw Attachment of Fracture Fixation Plates

G. S. Beaupré, N. J. Giori, W. E. Caler, and *J. Csongradi

*Veterans Affairs Medical Center, Rehabilitation Research and Development Center, Palo Alto; and *Division of Orthopaedic Surgery, Stanford University Medical Center, Stanford, California, U.S.A.*

Summary: Plate fixation is considered by many clinicians to be the treatment of choice for displaced diaphyseal fractures of the forearm. One possible complication associated with plate fixation is refracture with the plate in situ or after plate removal. With the plate in situ, refracture typically occurs through the last screw hole near the end of the plate. Some clinicians have advocated the use of unicortical end screws to minimize the risk of such refractures. In this study, we performed a series of in vitro tests to compare the breaking strength of plated bone analogues that used either unicortical or bicortical end screws. The plated constructs that used unicortical end screws were significantly weaker in the two most important physiologic loading modes. Based on these results, we conclude that the use of unicortical end screws may result in a greater risk of refracture with the plate in situ. **Key Words:** Bicortical/unicortical screw fixation—Refracture—Complications—Internal fixation—Fracture fixation—Dynamic compression plating.

Plate fixation is considered by many orthopaedic surgeons to be the treatment of choice for displaced diaphyseal fractures of the forearm (21). By providing near-anatomic reduction, and permitting an early return to motion, plate fixation of forearm fractures often leads to excellent functional results (6,20). Plate fixation is not without complications, however. Refracture is one possible complication which, although it does not happen frequently, represents a serious clinical concern. Refracture most often necessitates an additional surgical procedure with its own associated risk of complications, increased medical costs, increased healing time, and loss of productivity. Two types of refracture are possible with plated bones: (a) that which occurs after the plate has been removed; and (b) that which occurs with the plate in situ. The first type of refracture has received considerable attention (5,13, 15,21) and will not be discussed further. The second type of refracture, which has received minimal attention, is the exclusive focus of the present study. In particular, this study focuses on bone that refractures at or near the end of the plate. This type of refracture is illustrated in Fig. 1. In this hip arthrodesis case, the femur has fractured at the distal end of a cobra plate.

There are no definitive studies that specifically address the clinical frequency of refractures near the end of the plate, although some reports do exist both in the classic orthopaedic texts (14,17), and in the plating literature (1,5,8,19,23,24). Not all plating studies differentiate between refracture with the plate in situ and refracture after plate removal.

Address correspondence and reprint requests to Dr. G. S. Beaupré at Rehabilitation Research and Development Center (153), Veterans Affairs Medical Center, 3801 Miranda Avenue, Palo Alto, CA 94304, U.S.A.

Presented in part at the 1991 Annual Meeting of the American Academy of Orthopaedic Surgeons, Anaheim, CA U.S.A.

FIG. 1. Refracture after hip arthrodesis using a cobra plate. (Radiograph courtesy of Drs. V. H. Frankel and R. A. Winquist.)

Therefore, an accurate determination of the rate at which refracture with the plate in situ occurs is difficult to obtain. In the few studies that explicitly report refractures with the plate in situ, the rate of refracture has ranged from ~1–3% (1,5,8,19).

Refracture of the bone at the end of the plate has been reported to occur as a result of a stress concentration associated with the change in stiffness at the junction of plated and unplated sections of bone. In an attempt to make the load transfer from bone to plate more gradual, reduced stiffness plates (10,25), tapered plates (2,9,26), and unicortical end screws (14,17) have been suggested. The use of unicortical end screws is one approach that has found some clinical acceptance (5,6).

In discussing the use of unicortical end screws, the second edition of the AO Manual (17) states:

> The [end] screw is usually inserted through only one cortex. This results in a more gradual transition of forces under load between the plated segment and the rest of the bone, and the elasticity of the bone is not interrupted so suddenly.

In *Rockwood and Green's Fractures in Adults*, Harkess et al. (14) make a similar argument when they state:

> The short [end] screw gripping only one cortex is intended to smooth out the gradation between the normal elastic bone and the segment deep to the plate.

When discussing refracture, the AO Manual (17) also says:

> A particular type of refracture is the transverse fracture occurring at the junction of the relatively rigid plated segment, and that of the normally elastic diaphysis. For this reason, we aim at a gradual transition from the rigid to the less rigid segment of bone by inserting one or two short screws which go through only one cortex.

Despite these recommendations, many clinicians choose to attach plates using bicortical end screws. This practice is perhaps based on the belief that the use of bicortical end screws leads to a stronger fracture repair than does the use of unicortical ones. Few studies have examined this issue quantitatively (12,16). Our goal was to compare the breaking strength of plate/bone constructs that use unicortical end screws with those using bicortical end screws.

MATERIALS AND METHODS

To eliminate the variability inherent with testing cadaver bone, we developed a bone analogue made from paper-based phenolic tubing (Laminated Fabricators, San Bruno, CA, U.S.A.). Tensile tests of the phenolic tubing showed that its modulus (7.7 ± 0.2 GPa) and strength (81 ± 4.2 MPa) were ~50 and 60% of the values for cortical bone, respectively. The outer diameter and wall thickness of the tubing were chosen to match the mid-diaphyseal, cross-sectional area and moment of inertia of the human radius as determined in an earlier study (3). The resulting outer diameter was 13 mm, and the wall thickness was 2.5 mm.

The phenolic tubing was cut into sections 225 mm long. A transverse osteotomy was performed on each section of tubing, creating two equal-length "fracture" segments. Fixation of the two segments was accomplished using a Zimmer six-hole, titanium-alloy, dynamic-compression plate (catalog no. 8864-06, Zimmer, Warsaw, IN, U.S.A.). The plates were 73 mm long, 10.7 mm wide, and 2.8 mm thick. The plates were attached using titanium-alloy, cortical-bone screws (major diameter 3.5 mm, minor diameter 1.9 mm, pitch 1.75 mm). The screw holes were drilled and tapped using standard surgical instruments. Screw hole placement was determined using the appropriate drill guide in such a way that the screws were placed in the "neutral" position within the slotted holes in the plate.

The fixation plates were attached to the osteotomized bone analogue using one of two procedures. In the first group, the plates were attached using bicortical screws (22 mm long) at each of the six screw locations (Fig. 2, top). In the second group, the plates were attached using bicortical screws at the four inner screw locations, and unicortical

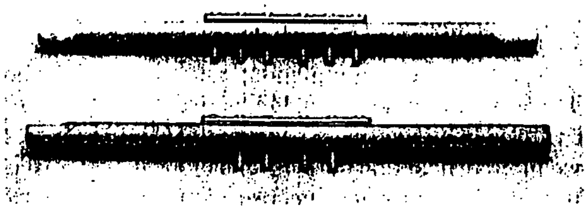

FIG. 2. Bone analogue with bicortical (top) and unicortical (bottom) end screws.

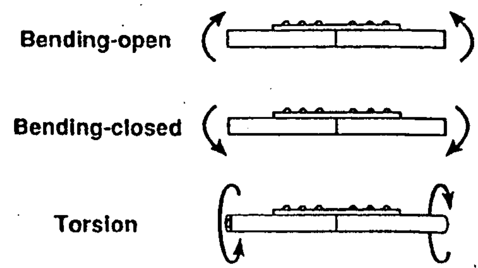

FIG. 4. The plated bone analogues were tested in three loading modes. Top: Bending-open; middle: bending-closed; bottom: torsion.

screws (12 mm) at the two outermost screw locations (Fig. 2, bottom). Each screw was tightened to a predetermined torque value using a custom-made torque-monitoring screwdriver (Fig. 3). Each bicortical screw was tightened to a torque value of 1.5 Nm, and each unicortical screw was tightened to a torque value of 0.75 Nm.

The plated bone analogues were subjected to both four-point bending and torsional loads (Fig. 4). The bending tests were performed in both the bending-open and the bending-closed loading modes. The bending tests were conducted at a constant displacement rate of 1.0 mm/s using a uniaxial materials testing machine (Model 858, MTS Systems Corp., Minneapolis, MN, U.S.A.). Twelve tests each were performed in both the bending-open and bending-closed loading modes. Torsion tests were conducted at a constant rotation rate of 50°/s with a torsion materials testing machine (MTS, Model 809). Ten torsion tests were performed.

Load–displacement curves were recorded during each test using an X–Y recorder. The maximum bending moment and maximum torque at failure were used as measures of strength of the bone-plate systems. The data were compared using the Student's t test.

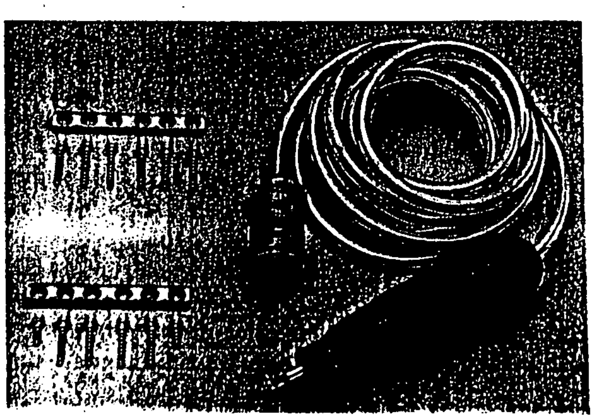

FIG. 3. Six-hole dynamic compression plates with bicortical and unicortical end screws. Custom-made torque screwdriver is also shown.

RESULTS

Fracture Description

Bending-Open

Typical fracture paths for the bending-open tests are shown in Fig. 5. The bicortical construct is shown at the top of the photograph. With bicortical end screws, the fracture line is transverse, and connects the outermost screw hole in the trans cortex (the cortex opposite the plate) with the cis cortex (the cortex directly under the plate) near the end screw hole and the plate end.

With unicortical end screws (bottom of Fig. 5), the fracture line is oblique, and connects the trans cortex at the second screw to the cis cortex near the outermost screw hole and the end of the plate. Substantial damage to the bone analogue is apparent in the cis cortex near the unicortical screw hole.

Bending-Closed

The fracture paths for the bending-closed tests are shown in Fig. 6. With bicortical end screws, the

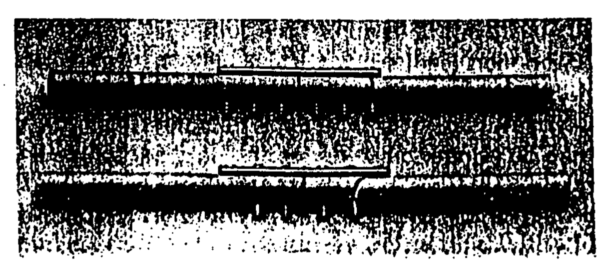

FIG. 5. Typical fractured bone analogues after bending-open tests. Top: Bicortical end screw construct; bottom: unicortical end screw construct.

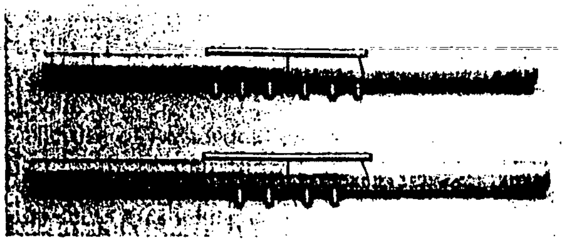

FIG. 6. Typical fractured bone analogues after bending-closed tests. **Top:** Bicortical end screw construct; **bottom:** unicortical end screw construct.

fracture connects the outermost screw hole in the cis cortex to the trans cortex at the outermost screw hole. The fracture is primarily transverse.

With unicortical end screws, the fracture line is slightly oblique. The fracture begins in the trans cortex almost directly across from the end of the plate, and proceeds upward to the outermost screw hole in the cis cortex. In none of the unicortical bending-closed tests did the fracture line involve a screw hole in the trans cortex.

Torsion

The fracture paths in the torsion tests were generally more complicated than those described earlier. However, as is typical of torsional fractures, the fracture always contained a spiral segment at ~45° to the longitudinal axis of the bone analogue. Fractured bone analogues after torsional testing are shown in Figs. 7 and 8. Two typical specimens that used bicortical end screws are shown in Fig. 7. The upper specimen shows the cis cortex with the outline of the plate drawn on the bone analogue. A spiral fracture occurs through the outermost screw hole in the cis cortex. The lower specimen in Fig. 7

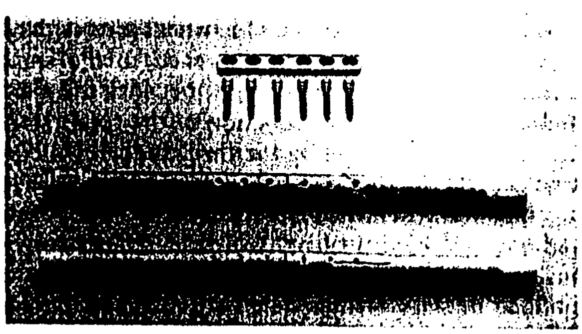

FIG. 7. Typical fractured bone analogues after torsional testing with bicortical end screws. **Top:** Cis cortex; **bottom:** trans cortex.

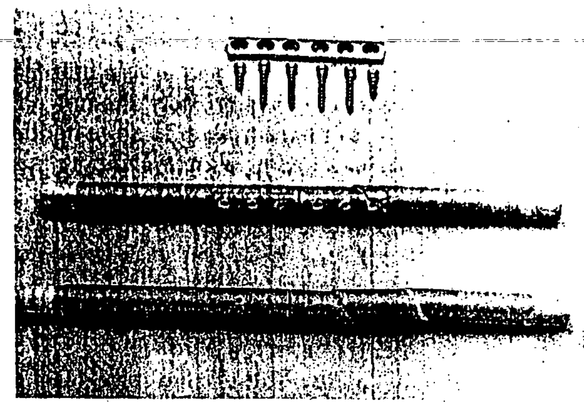

FIG. 8. Typical fractured bone analogues after torsional testing with unicortical end screws. **Top:** Cis cortex; **bottom:** trans cortex.

shows the trans cortex. With bicortical end screws, the fracture in the trans cortex always consisted of a longitudinal segment involving both the second and outermost screw holes.

Two typical specimens that used unicortical end screws are shown in Fig. 8. The upper specimen shows the cis cortex and the lower specimen shows the trans cortex. In the cis cortex, the unicortical screw hole is the focus of multiple fracture lines and substantial damage near the outermost screw hole. Unlike the bicortical situation described previously, the trans cortex (bottom of Fig. 8) involved a spiral component rather than a longitudinal segment.

Breaking Strength

A comparison of breaking strength for the three loading modes is shown in Fig. 9. For each loading mode, the breaking strength has been normalized by the mean value obtained from the bicortical tests for that particular loading mode. The error bars represent one standard deviation. Significant differences in breaking strength between the unicortical and bicortical constructs exist for each loading mode. In the bending-open loading mode, the use of unicortical end screw results in a bone-plate construct that is 40% stronger than the bicortical construct ($p < 0.01$). In the bending-closed and torsion loading modes, the opposite is true. The unicortical end screw construct is 12% weaker ($p < 0.05$) in the bending-closed mode than the bicortical end screw construct. In torsion, the unicortical end screw construct is 18% weaker ($p < 0.01$) than the bicortical construct.

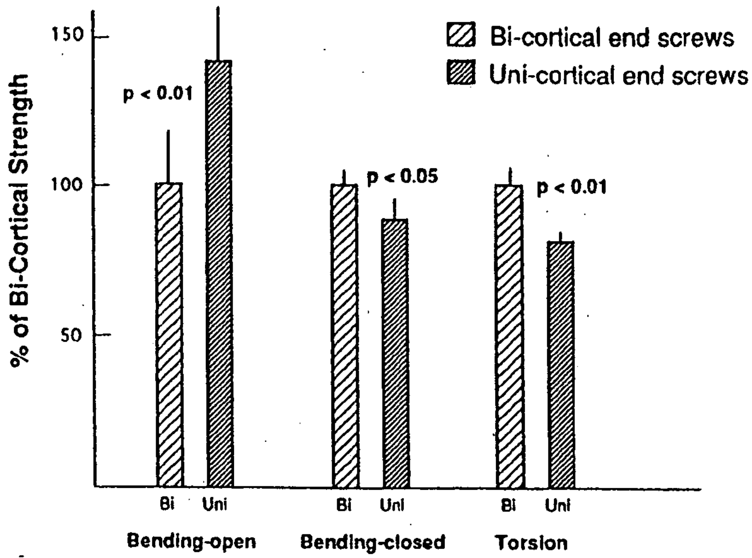

FIG. 9. Breaking strength for each of the three loading modes. For each loading mode, the breaking strength has been normalized by the mean value of the bicortical tests for that loading mode. Error bars represent one standard deviation.

DISCUSSION

This study shows that the breaking strength of a plate-bone system is a function of the type of end screws used. The use of bicortical end screws results in a stronger construct in both the bending-closed and torsion loading modes. Only in the bending-open loading mode does the use of unicortical end screws provide a stronger construct.

To understand why the use of unicortical end screws results in a stronger construct for the bending-open loading mode, we note that fractures typically initiate in regions of high-tensile stresses. In the bending-open loading mode, the trans cortex is the tension side, and, therefore, a refracture will initiate at the most highly stressed point in the trans cortex. Finite element models of plate-bone systems (3,7,22) have shown that the stresses increase with increasing distance from the fracture site, and that most of the load transfer occurs through the outermost screws. Because the outermost screw hole in the tension (trans) cortex in the bicortical construct is nearer to the end of the plate, the tensile stresses at this location will be higher than those in the unicortical system. This results in failure at a lower applied load in the bicortical system.

In the bending-closed loading mode, the cis cortex is now the tension cortex. In this case, the outermost screw hole in the tension cortex for both the unicortical and bicortical constructs is highly stressed. However, for both the bending-closed and torsion loading modes, there is no obvious reason why the stresses near the unicortical end screw would be higher than those near the bicortical end screw. At the 1977 AO course in Davos, Switzerland, Frankel first suggested that the use of unicortical end screws was deleterious (personal communication). Frankel argued that the load transfer from the bone to the plate is different for the unicortical and bicortical constructs. He further argued that with bicortical end screws, both cortices participate more or less equally in the load transfer. In the unicortical system, only the cis cortex participates in load transfer near the end of the plate; the cis cortex, therefore, will be more highly stressed. A critical investigation of this hypothesis would require a careful experimental (e.g., strain gage) or finite element study.

Another hypothesis is based upon the difference in stability of unicortical and bicortical screws. Unicortical screws cannot be tightened to the same torque level as bicortical screws, because the maximum screw torque is a function of the total thickness of cortex engaged by the threads (11). Unicortical screws may therefore be more susceptible to toggling in the screw hole because they are looser, and because bicortical or two-point fixation obviously provides more stability against this type of motion. Bechtol (4) has made a similar argument. This toggling may damage the screw thread–bone interface, thereby weakening the system. The damage in the cis cortex near the unicortical screw hole

in our tests may be an indication of the effect of toggling. It is not unreasonable to think that the arguments made by Frankel and Bechtol are both relevant.

The use of unicortical end screws with plate fixation has been suggested as a way to decrease the likelihood of bone refracture with a fracture fixation plate in situ (14,17). It is interesting to note that the latest edition of the AO manual (18) no longer contains many of the arguments in the text supporting the use of unicortical end screws that appeared in the previous edition (17). However, many of the figures in the latest edition, which are identical to the figures in the previous edition, still illustrate the use of unicortical end screws

In the widely used orthopaedic reference, *Rockwood and Green's Fractures in Adults,* Harkess et al. (14) also recommend the use of unicortical end screws. Both the language and the illustrations related to unicortical end screws that appear in Rockwood and Green are based upon the second edition of the AO manual (17). Because the AO Manual and Rockwood and Green are two of the most important clinical references on plate fixation, some clinicians will use unicortical end screws based solely on recommendations contained in these classic texts.

The only previous studies that compared the use of unicortical and bicortical end screws concluded that there were no significant differences in strength between the two constructs (12,16). Hopf et al. (16) tested the failure strength of five matched pairs of fresh human femora with 10-hole plates attached to the lateral midshaft. One femur in each pair had unicortical end screws, and the other had bicortical end screws. Some of the matched pairs were tested in the bending-open loading mode; others were tested in the bending-closed loading mode. Unfortunately, the authors did not specify the number of specimens tested in each mode, nor did they report the numerical values of the breaking strength. They also stated that the small sample sizes prevented them from performing any statistical analyses. Their study is further complicated by the fact that multiple-load cycles were used in the bending-open tests, whereas a single load-to-failure protocol was used for the bending-closed tests. As a result, there is no quantitative evidence to support their conclusions regarding breaking strength.

Davenport et al. (12) performed an in vitro study in which they attached narrow, six-hole, stainless-steel dynamic-compression plates using 4.5-mm screws to both intact and osteotomized canine femora. One femur in each matched pair was plated using uni-cortical end screws, while the contralateral femur was plated using bicortical end screws. The femora were tested to failure in torsion. Although none of their strength results reached statistical significance, the mean value of failure torque in their osteotomized series was 16% higher in the bicortical group than in the unicortical group. This compares very favorably with the 18% higher failure torque for the bicortical construct under torsional loading that we found in our study.

The studies by Hopf et al. (16) and Davenport et al. (12) point out the difficulties inherent in the use of real bones in studies that require mechanical testing. Variations in mechanical properties (e.g., strength and stiffness) from bone to bone, even when using matched pairs, can require large sample sizes to show statistically significant differences between groups. The use of a bone analogue in these types of studies offers a distinct advantage. Because interspecimen variability is minimal for bone analogues, statistical significance can be found using sample sizes that might produce only trends or nonsignificant differences if real bones were used. The use of a bone analogue, however, does raise an important question. That is, does the use of a bone analogue accurately reflect the response of the real bone? Unfortunately, we know of no manufactured materials that have the exact same properties as bone. However, the phenolic material used in the present study has properties that are at least similar to those of bone. We feel that the results of our mechanical tests using a bone analogue do adequately represent the response that would occur in real bone. A comparison of the trends found by Davenport et al. (12) with our results would seem to support this conclusion.

This study does not address potential long-term effects related to the use of unicortical or bicortical end screws. In addition to breaking strength, the stability of fixation (12,16) and the extent of adverse bone remodeling (e.g., plate-induced osteopenia) can also be affected by the type of end screws. These important issues await further study. This study does show that the use of bicortical end screws rather than unicortical end screws will result in a stronger plate-bone construct for two of the most important physiologic loading modes, namely bending-closed and torsion. These two loading modes are unquestionably the most important ones for the type of fixation shown in Fig. 1.

Although the unicortical construct is stronger in

the bending-open loading mode, the recommendation to use unicortical end screws cannot be based solely on this finding. By considering the predominant in vivo loading modes, we conclude that bicortical end screw fixation should result in a fracture repair less susceptible to refracture with the plate in situ.

Acknowledgment: This work was supported by the Department of Veterans Affairs, Rehabilitation Research and Development Service through Merit Review. We would like to thank Jim Anderson for machining the phenolic tubes and for providing much appreciated technical advice. We would also like to express our appreciation to Victor Frankel, M.D. and Jacques Cordey, Dr.Sc. for their recollections of Dr. Frankel's comments at the 24th AO Course in 1977 related to the use of unicortical end screws.

REFERENCES

1. Anderson LD, Sisk TD, Tooms RE, Park WI: Compression-plate fixation of acute diaphyseal fractures of the radius and ulna. *J Bone Joint Surg [Am]* 57:287–296, 1975.
2. Beaupré GS, Carter DR: Mechanisms to alter load transfer along the diaphysis in plated bones. *Trans Orthop Res Soc* 12:386, 1987.
3. Beaupré GS, Carter DR, Orr TE, Csongradi J: Stresses in plate long-bones: the role of screw tightness and interface slipping. *J Orthop Res* 6:39–50, 1988.
4. Bechtol CO: Engineering principles applied to orthopaedic surgery. In: *Instructional Course Lectures*, ed by CH Pease, Ann Arbor, JW Edwards, 1952, pp 257–264.
5. Böstman OM: Refracture after removal of a condylar plate from the distal third of the femur. *J Bone Joint Surg [Am]* 72:1013–1018, 1990.
6. Chapman MW, Gordon JE, Zissimos AG: Compression-plate fixation of acute fractures of the diaphysis of the radius and ulna. *J Bone Joint Surg [Am]* 71:159–169, 1989.
7. Cheal EJ, Hayes WC, White AA, Perren SM: Stress analysis of compression plate fixation and its effects on long bone remodeling. *J Biomech* 18:141–150, 1985.
8. Cheng JCY, Tse PYT, Chow YYN: The place of the dynamic compression plate in femoral shaft fractures. *Injury* 16:529–534, 1985.
9. Comtet JJ, Moyen BJL, Meyrueis JP, Santini R, Rumerhart C, Borgi R, Millan JJ: Plate of variable flexibility: mechanical and biologic study on intact femora of dogs. In: *Current Concepts of Internal Fixation of Fractures*, ed by HK Uhthoff, Berlin, Springer-Verlag, 1980, pp 379–388.
10. Corcoran SF, Koroluk JM, Parsons JR, Alexander H, Weiss AB: The development of a variable stiffness, absorbable composite plate. In: *Current Concepts of Internal Fixation of Fractures*, ed by HK Uhthoff, Berlin, Springer-Verlag, 1980, pp 136–145.
11. Cordey JR, Rahn BA, Perren SM: Human torque control in the use of bone screws. In: *Current Concepts of Internal Fixation of Fractures*, ed by HK Uhthoff, Berlin, Springer-Verlag, 1980, pp 235–243.
12. Davenport SR, Lindsey RW, Leggon R, Miclau T, Panjabi M: Dynamics compression plate fixation: a biomechanical comparison of unicortical vs bicortical distal screw fixation. *J Orthop Trauma* 2:146–150, 1988.
13. Deluca PA, Lindsey RW, Ruwe PA: Refracture of bones of the forearm after the removal of compression plates. *J Bone Joint Surg [Am]* 70:1372–1376, 1988.
14. Harkess JW, Ramsey WC, Harkess JW: Principles of fractures and dislocations. In: *Rockwood and Green's Fractures in Adults*, 3rd ed., vol. 1, ed by CA Rockwood, DP Green, RW Bucholz, Philadelphia, J. B. Lippincott, 1991, pp 103, 107.
15. Hidaka S, Gustillo RB: Refracture of bones of the forearm after plate removal. *J Bone Joint Surg [Am]* 66:1241–1243, 1984.
16. Hopf TH, Scheuermann O: Die Bedeutung der endständigen Schraube bei der Plattenosteosynthese im Hinblick auf das Verformungsverhalten des Knochens unter dem Plattenende. *Unfallchirugie* 90:41–43, 1987.
17. Müller ME, Allgöwer M, Schneider R, Willenegger H: *Manual of Internal Fixation: Techniques Recommended by the AO-Group*, 2nd ed., Berlin, Springer-Verlag, 1979, pp 54, 153.
18. Müller ME, Allgöwer M, Schneider R, Willenegger H: *Manual of Internal Fixation: Techniques Recommended by the AO-ASIF Group*, 3rd ed., Berlin, Springer-Verlag, 1991.
19. O'Beirne JO, O'Connel RJ, White JM, Flynn M: Fractures of the femur treated by femoral plating using the anterolateral approach. *Injury* 17:387–390, 1986.
20. Ross ERS, Gourevitch D, Hastings GW, Wynn-Jones CE, Ali S: Retrospective analysis of plate fixation of diaphyseal fractures of the forearm bones. *Injury* 20:211–214, 1989.
21. Rosson JW, Shearer JR: Refracture after the removal of plates from the forearm. An avoidable complication. *J Bone Joint Surg [Am]* 73:415–417, 1991.
22. Simon BR, Woo SL-Y, Stanley GM, et al: Evaluation of one-, two-, and three-dimensional finite element and experimental models of internal fixation plates. *J Biomech* 10:79–86, 1977.
23. Stern PJ, Drury WJ: Complications of plate fixation of forearm fractures. *Clin Orthop* 175:25–29, 1983.
24. Teipner WA, Mast JW: Internal fixation of forearm diaphyseal fractures: double plating versus single compression (tension band) plating—a comparative study. *Orthop Clin North Am* 11:381–391, 1980.
25. Woo SL-Y, Simon BR, Akeson WH, Gomez MA, Seguchi Y: A new approach to the design of internal fixation plates. *J Biomed Mat Res* 17:427–439, 1983.
26. Xu XX, Shi DG, Qi B, Dong SC, Lu XM: A newly designed trapezoid compression plate. *Proceedings of the Fourth Meeting of the European Society of Biomechanics*, pp 278, 1984.